Chapter 5

METHODS FOR PROJECTING AREAS OF PRIVATE TIMBERLAND AND FOREST COVER TYPES

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Abstract. We summarize methods used to project area changes in land uses and forest cover types in the national RPA Timber Assessments over the last 20 years, since area projection modeling systems replaced expert opinion approaches. Such models reflect that key land base changes such as afforestation and deforestation are driven by quite different socioeconomic factors. The prototype area-change modeling system—the AREACHANGE projection system—was constructed in the early 1980s for the South to support a special study between periodic RPA Timber Assessments. The southern prototype involved an area-base econometric approach, which has been applied in later RPA Timber Assessments regions and revised for the South. Other econometric models were developed in the late 1980s and later decades for the Pacific Northwest, Lake States, Maine, and other regions. Timber price projections from the Timber Assessment Projection System's modeling of markets are used as inputs in the first stage of the area-change projections. Timber harvest projections from the TAMM model, as allocated to management units by the ATLAS model, along with timber management projections from the ATLAS model are used as inputs in the second stage of projecting area changes in major forest cover types. The AREACHANGE system provides the ATLAS system with projections of timberland area by region, ownership, and major forest type. The progression of area-change modeling was heavily dependent on the availability of land-use data.

Keywords: land allocation, area change projections, forest type transitions

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5.1 INTRODUCTION

This chapter summarizes the history of area projection methods in large-scale assessments, development of land-use models based on land rent theory, and development of forest cover models based on combining ecological and economic theories of forest cover changes. Over the last 25 years, renewable resource assessments have addressed demand, supply, and inventory of various renewable resources in increasingly sophisticated fashion, including simulation and optimization analyses of area changes in land uses (e.g. urbanization) and land covers (e.g. plantations vs. naturally regenerated forests). This chapter centers on methods used in the national RPA Timber Assessments since area projection modeling systems replaced expert opinion approaches 20 years ago (e.g. Wall 1981). Such models reflect that key land base changes such as afforestation and deforestation are driven by quite different socioeconomic factors. Projections of area changes are important for a wide range of natural resource analyses, including those for wildlife habitat, timber supply, global climate change, water, recreation, and others.

5.2 HISTORY AND SCOPE OF LARGE-SCALE FOREST AREA-CHANGE PROJECTIONS

Information needs that guided development of area-change models centered on policy-relevant questions that reflect the many demands for information about the current and future land base. The core research described here was designed to support a broad set of large-scale assessments of natural resource situations and prospects, as part of the national and periodic RPA Resource Assessments. Given the national scope, research on methods to project area change was designed to provide region-wide projections in order to effectively interface with other large-scale models used in the RPA Timber Assessments that drew upon a national network of regional modeling of forest growth and yield and timber harvest.[1] Before the early 1980s, estimates of future timberland area generally were based on subjective opinions of experts, an approach illustrated by Wall (1981). Alig et al.

[1] The Timber Assessment and related studies were the testing ground for forest area projections methods because they used the most comprehensive analytical frameworks.

(1983) called for new approaches in projecting long-range projections of timberland area to explicitly and systematically consider major forces that influence land use, such as regional patterns of population growth. In addition, models were needed that could project area changes for major forest types on private timberland.

Addressing the information needs has resulted in essentially three phases in the RPA history of area-change modeling studies and in implementing a land area projection system, AREACHANGE, to project land-use and forest type changes at regional and national scales. The first phase supported the 1989 RPA Timber Assessment, the second supported the 2000 RPA Timber Assessment, and the ongoing third phase is in support of the 2010 RPA Assessment. These phases reflect differences by region of the USA pertaining to resource conditions and land productivity for forestry, likelihood of area changes affecting private forests (e.g. relative growth in developed uses in the South), the likely policy relevance of forest area changes in a region, and the availability of land-use data, especially time series, with which to develop models of land-use change. Given limited resources, the first priority in the first phase was to develop area-change projection methods for the South (Wear and Greis 2002). In the 1980s, surveys of forest resources were showing that net annual timber growth, after rising for decades, had begun to decline. Softwood timber removals were exceeding net annual growth over large areas, and timber inventories were beginning to decrease. Part of this was thought to be related to changes in the land base. Developing systematic and explicit models of the relationships among the key determinants and timberland area for major forest cover types was designed to investigate how the quantity and quality of land in timber production serve as major determinants of macro timber supply and prices. The prototype area-change modeling system used an area-base econometric approach for the land-use projections to support a special study of *The South's Fourth Forest*, between periodic RPA Timber Assessments (USDA FS 1988).

Developing land use and landcover estimates for *The South's Fourth Forest* study defined the first phase of RPA land-use and land-cover modeling. These models captured the complex interactions between land-use changes and socioeconomic (e.g. population) and other variables for the Southeast (Alig 1985, 1986). The model was applied to project area changes for forest industry, miscellaneous corporate owners, and farmers and other private owners. For each of those owner groups in the South, area changes for major forest cover

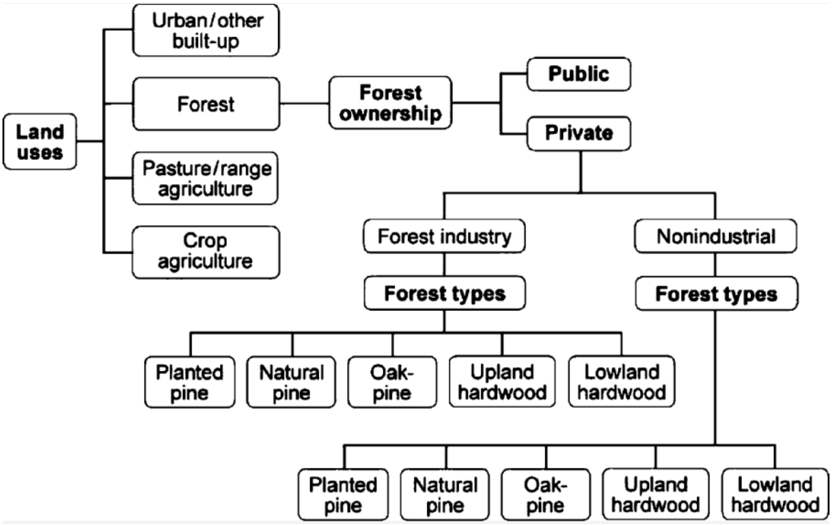

Figure 5-1. Schematic of land uses and relations of overall land-use modeling to that for forest cover types for RPA Timber Assessments, with example of forest cover types for the South.

types—planted pine, natural pine, oak-pine, upland hardwoods, and bottomland hardwoods (Figure 5-1)—were then projected for 50 years (Alig 1985). In this phase, the South was the only region for which models were developed to project changes in forest cover types. *The South's Fourth Forest* study also represented an advancement in linking models—such as the Southern Area Model (SAM) (Alig 1985), a predecessor to the ATLAS model (Tedder et al. 1987; Mills and Kincaid 1992), and TAMM (Adams and Haynes 1980)—that would be further integrated in subsequent RPA Timber Assessments.

As part of the first phase of modeling land-use change models were developed for the South Central region using the area-base approach (Alig et al. 1988), the Pacific Northwest West (Parks 1988; Parks and Murray 1994), the Northeast with heavily forested states (e.g. Maine) (Howard and Lutz 1991), and the Lake States with substantial timber volumes (Plantinga et al. 1989, 1990). Similar to the original model for the Southeast that used an area-base approach, models for other regions employed econometric analyses of land-use determinants by region, as a basis for developing simulation models to project regional area changes in timberland on private ownerships. Land-use competition between forestry and competing sectors (e.g. agriculture)

is guided by land rent theory and estimated with econometric models of relationships between changes in timberland area and determinants such as population, per capita income, and income from land based enterprises such as forestry or agriculture. Results from these first-generation models were applied in the 1989 RPA Land Base Assessment (USDA FS 1989).

In the second phase of area-change model building in the 1990s, the aim was to support the 2000 RPA Timber Assessment and other RPA Resource Assessments. Table 5-1 lists the land-use and forest type cover modeling studies by region used to support the 2000 RPA Timber Assessment and subsequent interim 2005 RPA Timber Assessment (Haynes et al. 2007). Alig et al. (2003) and Alig and Butler (2004a) provide more details on region-specific models. Given advances in data availability, second-generation land-use models were developed in the 1990s that included a mixture of primary data sources pertaining to land use. Such models also had the benefit compared to first-generation models of longer time series data available to estimate parameters for most of the behavioral relations. For example, the study by Mauldin et al. (1999b) to update the Lake States modeling used Forest Inventory and Analysis (FIA) data for forest land (including some data from the 1990s), Census of Agriculture data for agricultural land, USDA data on land quality, and census of population and housing for urban and developed land; in contrast, the earlier Plantinga et al. (1989) study was largely restricted to FIA data.

The third phase of RPA land-use model building started in the 2000s to support the 2010 RPA Assessment (Alig 2005). The third phase involves substantial changes in area-change studies and the AREACHANGE approach. Notable changes between the second and third phases include (1) development of a national land-use model with regional detail; (2) land-use transition (e.g. forest to agriculture) modeling in contrast to earlier modeling of levels or amounts of separate land uses; and (3) county-level projections of land-use changes. Land-use modeling in the third phase covers all regions. In the first and second phases, formal regional models had not yet been developed for regions such as the Pacific Southwest, Pacific Northwest East, Rocky Mountains, Great Plains, and the Corn Belt (Alig et al. 2003).

The description of methods in this chapter follows the priority assigned to regions in developing regional area projection models in phases 1 and 2. Therefore, the modeling framework for the South—the location of the prototype regional area-base model—will receive the

Table 5-1. Studies supporting development of timberland area projections by region for the 2000 RPA Timber Assessment

Region	States	Land-use study	Forest type transition study
North:			
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia	Plantinga et al. (1999a), Mauldin et al. (1999a)	
North Central	Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin	Mauldin et al. (1999b), Choi et al. (2001)	
South:			
Southeast	Florida, Georgia, North Carolina, South Carolina, Virginia	Plantinga and Ahn (2000)	Alig and Butler (2004b)
South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	Ahn et al. (2001, 2002)	Alig and Butler (2004b)
Rocky Mountain:			
Great Plains	Kansas, Nebraska, North Dakota, South Dakota		
Intermountain	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming		
Pacific Coast:			
Alaska	Alaska		
Pacific Northwest West	Western parts of Oregon and Washington, West of the crest of the Cascade range	Zheng and Alig (1999), Kline and Alig (2001)	Alig et al. (2000)
Pacific Northwest East	Eastern parts of Oregon and Washington, East of the crest of the Cascade range		
Pacific Southwest	California, Hawaii		
USA		Alig et al. (2003)	Alig and Butler (2004a)

most treatment in this chapter. Although we will emphasize studies listed in Table 5-1 that supported the 2000 RPA Timber Assessment and the subsequent 2005 RPA Timber Assessment (Haynes et al. 2007), we will also briefly discuss subsequent modeling advances that are part of the current phase 3.

A key point well demonstrated in *The South's Fourth Forest* study (USDA FS 1988) was that the progression of area-change modeling was heavily dependent on the availability of land-use and forest cover type data. Early land-use models applied in the RPA Timber Assessment framework were based on FIA data (e.g. Alig 1986), which center on forestland and typically do not report on transitions among land uses or estimate area changes for nonforest uses. One advantage to using FIA data for constructing land-use and land-cover models was consistency with data used by other RPA Timber Assessment models, especially the ATLAS modeling system (Mills and Kincaid 1992) described in Chapter 6. Disadvantages to using the FIA data compared to broader data sets on land use were the lack of land-quality data for multiple land uses and representation of two-way flows among land uses, also needed in other RPA Resource Assessments. Models planned for application in the 2010 RPA Assessment draw on such transition data from the USDA's Natural Resources Inventory (NRI), and an example is discussed by Lubowski et al. (2006).

In terms of definitions, this chapter focuses on land-use and land-cover changes on private lands that involve forestry.[2] Land use is the purpose to which land is put by humans, e.g. protected areas, forestry for timber products, plantations, row-crop agriculture, pastures, or human settlements (Alig et. al. 2003). Land cover is the observed biophysical cover on the Earth's surface, e.g. oak-hickory forest (Alig and Butler 2004a). Timberland is a subset of forestland that meets a timber productivity criterion and is available for timber harvest and related operations (Smith et al. 2004). Earlier reviews of land base models are provided by Alig et al. (1984), Parks and Alig (1988), Alig (2005), and Plantinga and Irwin (2006).

[2] For 2002, the total revenue from timber harvests on private lands was approximately $9 billion, compared to $900 million for that from public timberlands. Data sources include timber harvest estimates from the Forest Service (http://www.fs.fed.us/forestmanagement/reports/sold-harvest/index.shtml), timber harvest estimates for other public and private lands from Haynes et al. (2007), and timber price data from the Timber Assessment database (Darius Adams, personal communication).

5.3 STRUCTURE OF LAND-USE AND LAND-COVER MODELING

The land area projection system, AREACHANGE, was developed to project land use and forest type changes at regional and national scales. Projections of area changes are accomplished in two stages: (1) projections of land-use changes, such as a shift from agriculture to forestry; and (2) projection of forest cover types, including planted pine, on land allocated to forestry. The projection system is based on biophysical, ecological, and economic criteria, and includes detail on forest ownership classes. In Section 5.4, we discuss methods used to project land-use changes, including theory used to guide empirical model estimation. Then, in Section 5.5 we discuss modeling forest type transitions.

Modeling the land-use component of timberland area changes in stage 1 of AREACHANGE focuses on the major competing land uses—forestry, agriculture, and urban and developed uses. Changes in land use such as clearing for development, tree planting, or natural seeding of trees on former agricultural land affect the total timberland area on a private forest ownership. The output of the stage 1 modeling—area changes in timberland by private forest ownership—serve as input for the second stage, where area changes by forest types are projected. Projecting changes in the areas of forest types accounts for forest succession and human-related disturbances (e.g. timber harvest) that influence future timber production. Using specific estimates for FI versus NIPF ownerships reflects behavioral differences in land management and investment, represented by the chosen mixture of timber harvest, tree planting, and other forest management activities.

The area-change modeling system was linked to the ATLAS and TAMM models in the 1989 RPA Timber Assessment (USDA FS 1990), drawing upon experiences from model linkages in *The South's Fourth Forest* study (USDA FS 1988). Coordinating area-change models within the RPA Timber Assessment constellation of models (see Figure 2-1, for schematic of linked assessment models) was important because of the sensitivity of projected changes in timber products markets to future timberland area patterns. For example, if land use is governed by economic considerations, then timberland area loss could lead to higher timber prices and would lessen the financial motivation to convert timberland. This suggested an iterative solution of linked

models to adequately capture such feedbacks, particularly price and timber harvest vectors provided by other RPA Timber Assessment models. See Chapter 8 and Haynes et al. (2007) for a more detailed discussion of the linkages and the handling of feedbacks among the constellation of models in the RPA Timber Assessment framework.

Connections within the system of models can involve both spatial (e.g. interregional shifts in timber production) as well as temporal aspects. For example, timber price projections from the TAMM/NAPAP modeling of markets are used as inputs in the first stage of the area-change projections. Timber harvest projections from the TAMM model, as allocated to management units by the ATLAS model, along with timber management projections from the ATLAS model are used as inputs in the second stage of projecting area changes in major forest cover types.

Inputs or feedbacks flow both ways in the Timber Assessment Projection System (hereafter, the Assessment System). The AREACHANGE system provides the ATLAS system with projections of timberland area by region, ownership, and major forest type. This linkage is facilitated by the area basis of both models; that is, the ATLAS model uses area cells or strata as described by FIA regional data. Within ATLAS, one stratum may be Southeast, FI, Planted Pine, High Timber Management Intensity, and High Site (other descriptors, e.g. age class, may be used by ATLAS that are not represented directly in the area-change models, see Chap. 6).

The AREACHANGE models used in the 2000 RPA Resources Assessments also indicated net changes, plus or minus, in timberland. This affects the ATLAS categorization of land base changes that in turn affect the connection to TAMM/NAPAP modeling. For example, deforestation is one of the four major types of area changes for forest types on a particular ownership, where the other three are afforestation, forest type transitions on retained timberland, and ownership exchanges. Deforestation involving mature timber could mean that at least some of the timber removed before land conversion could be processed at mills. The amount would affect ATLAS's modeling of the forest resource and would affect the TAMM/NAPAP modeling of timber markets, given the timber supply from "real estate harvests". Other types of interactions are discussed for the timber supply case by Alig et al. (1984), in describing potential linkages among models used to represent the following activities: land allocation, timber growth and yield, timber harvest, and timber investment. In recent years,

additional modeling components have been added to model forest carbon, biodiversity, wildlife habitat (e.g. Matthews et al. 2002), and other forest-based goods and services. A larger constellation of linked models over time has meant more potential feedback loops.

5.4 LAND-USE MODELING

In the case of land-use modeling, the basic approach is to use land rent theory to guide the estimation of the relationship between the area of land in alternative uses (forest, cropland, etc.) and key determinants influencing land-use decisions (e.g. net economic returns to land in different uses). Area-base models allocate proportions of a given land base to predefined land-use categories, such as forest. In Section 5.4.1, we describe the theory underlying the area-base land-use models and related models applied in RPA Timber Assessments.

5.4.1 Land-use theory

The allocation of land to alternative uses has been a topic of study at least since Ricardo's work pertaining to land rents and soil fertility and von Thünen developed his spatial model of land use in the mid-19th century. In modern times, Barlowe (1958), Alonso (1964), and others developed theoretical models of land allocation in the von Thünen tradition. As with von Thünen, these models explain how land-use patterns arise from spatial differences in land rents together with rent maximization by landowners. As discussed in Section 5.4.2, in recent decades economists have also developed empirical models that attempt to explain observed land-use patterns in terms of relative land rents.

Land-use models developed for RPA Resource Assessments have focused on the decisions by private landowners to allocate their land to alternative uses. It is assumed that landowners seek to maximize the economic returns (i.e. present value of net benefits) to their land. We begin by describing the basic model of land allocation, which provides the fundamental principles that underlie nearly all economic models of land use. We then discuss other factors that have been considered in RPA Resource Assessment analyses, including heterogeneous land quality and inter-temporal or dynamic influences. This discussion is based on Segerson et al. (2006).

5.4.1.1 The basic land allocation model

Since the earlier work by von Thünen and Ricardo, many authors have represented the land allocation problem, and here we will use a fairly simple representation of the landowner's problem of allocating a fixed amount of land to alternative uses (see, e.g. Alig 1986; Plantinga 1996; Miller and Plantinga 1999; Ahn et al. 2000). In general, economic models of land use are usually based on a profit maximization assumption that the landowner chooses a land use that maximizes the net present discounted returns from the land parcel over an infinite time horizon. The choice of a particular land use is made by comparing the net present value of the profitability of all possible land uses. Following Nelson and Hellerstein (1997), if we assume that a given land use has a single marketed product, the net present value of the return to that land use, its net present rent (R_{uj}) at time T can be written as:

$$R_{ujT} = \int_{t=0}^{\infty} (P_{ujT+t}Q_{ujT+t} - C_{ujT+t}X_{ujT+t})e^{-rt}dt \tag{5.1}$$

where P is the output price, Q is the quantity of output, C is a vector of input prices, X is a vector of inputs under operator control, and r is the discount rate, all for each land use u at location j at time t.

Assuming that the landowner will choose the land use that maximizes R_{ujt}, parcel j will be devoted to land use u if $R_{ujt} > R_{ljt}$ for all $l \neq u$. Given that not all factors that affect R_{ujt} are observable, this condition can be rewritten in a probabilistic framework in which the systematic and random portions of R_{ujt} are explicitly modeled. Assuming a distribution for the error terms and a functional form for the systematic portion, this model can be estimated using discrete choice methods, as discussed in Section 5.4.2.

In a forestry context, at the start of period t, the landowner decides whether to harvest trees or continue to grow trees in an existing stand or whether to reallocate the land to an agricultural or urban and developed use during the period. Ahn et al. (2000) lay out the analytical framework for comparing the net present value of expected net returns from alternative land uses, where land conversion costs are assumed to be included in the net return measures. The optimal shares of the land base occupied by major uses are influenced by land-quality factors embedded as well in the net return functions.

5.4.1.2 Incorporating land quality and other refinements

The capability to analyze the influence of land quality in large-scale assessments became possible with increasing data availability from surveys focused on agricultural measures. The NRI (USDA NRCS 2001) by the early 1990s provided available measures of land quality for large parts of the country. This allowed analysis of how the return from a particular land use depended on the physical characteristics of the land, such as soil type, slope, and water-holding capacity, in addition to attributes of the landowner such as managerial skill. Assume for simplicity that the vector of land characteristics can be summarized by a variable termed "land quality", denoted q, where $0 \leq q \leq 1$. If per hectare returns are independent of the amount of area allocated to each use, then the per hectare returns can be written $r_F(q)$ and $r_A(q)$, for returns to forestry and agriculture respectively. Land quality is defined so that returns are increasing for higher values of q. Typically returns to forest are higher than returns to agriculture on low-quality land (and vice versa).

The decision rule for the landowner is then to allocate a hectare of quality q land to forest if $r_F(q) \geq r_A(q)$ and, otherwise, allocate the land to agriculture. If the per hectare return functions intersect once, then a cut-off or threshold value of land quality, q^*, is defined as $r_F(q^*) = r_A(q^*)$. All land with quality below q^* will be allocated to forest and all land with quality above q^* will be put into agriculture. This result provides a convenient way of representing the aggregate allocation of land to each use. If $g(q)$ equals the share of land within a region (e.g. county, state) that is of quality q, then the total amount of land devoted to forest and agriculture, A_F and A_A, can be represented as:

$$\begin{aligned} A_F &= \int_0^{q^*} g(q)dq \\ A_A &= \int_{q^*}^{1} g(q)dq \end{aligned} \tag{5.2}$$

Examples of controlling for heterogeneous land quality in land-use studies at an aggregate level (e.g. county) are given by Plantinga (1996), Hardie and Parks (1997), Plantinga et al. (1999b), and Mauldin et al. (1999a). The NRI data containing land-quality measures provide many cross-sectional but few time series observations and, thus, most of the observed variation in land use is spatial (across county) variation. The challenge is to adequately control for differences across counties so that the more limited data on forest area over time can be used to estimate the temporal relationships of interest. Alig et al.

(2005) and Lewis and Plantinga (2007) discuss applications using parcel level or census tract data to investigate the spatial configuration of land quality and land use. Such advances may improve analyses of forest fragmentation in a landscape context (Lewis and Plantinga 2005), as well as the study of the effects of increased housing densities on remaining timberland (e.g. Kline et al. 2004; Stein et al. 2005).

In addition to varying with land quality, we noted that the returns to alternative land uses can vary over time. For instance, temporal variation in returns can arise from exogenous changes in factors that affect returns, such as changes in input or output prices over time. Temporal variation in returns affects the land allocation decision when forestry and agricultural uses are alternatives because of differences in the periodicity of returns. Agricultural returns are often realized on an annual basis, whereas returns to forestry are realized periodically (e.g. at the end of a harvest cycle). In general, this greatly complicates the land allocation decision. A decision to put the land into forestry today must be weighed against putting it into forest next period, or any period beyond that.

In earlier land-use analyses for RPA Resource Assessments, different land income expectation structures (e.g. lags) and simplifying assumptions were made to address the complicated dynamic allocation problem. For example, Plantinga (1996) shows that if landowners have static expectations (i.e. they expect future returns to be equal to the current return) and the land is initially bare, then in every period it is optimal for the landowner to choose the use generating the largest present discounted value of per hectare returns. The development of FASOM (Adams et al. 1996) provided an intertemporal optimization approach to analyzing land-use changes over times in an economic optimization framework. In the FASOM approach, the maximization of producers' and consumers' surpluses in the objective function leads to intertemporal optimization of private land use allocation decisions by region.

Many land-use analyses for RPA Resource Assessments have used the area-base econometric approach to model the allocation of land to forest, agricultural, and urban uses, and Ahn et al. (2000) found that such econometric land-use models are effective tools for projecting forest area. They point out that the models are particularly useful for policy analysis because they explicitly measure landowner responses to decision variables that can be affected by land-use policies. For example, Plantinga et al. (1999b) examine the effects of afforestation subsidies on land-use decisions by simulating increases in rents from

forestry. Limitations of this approach include reliance on the assumption that there are no significant changes in the underlying structural relationships. However, the model structure is shaped by the policy environment, and this changes over time. Ahn et al. (2000) provide the example that between 1962 and 1992 US farm programs were modified frequently, and the Conservation Reserve Program introduced in 1986 encouraged the establishment of permanent vegetative cover including trees. Statistical tests can be used to test for changes in model parameters over time, but a greater challenge is posed by the possibility of structural changes in the future. Future national Farm Bills, including changes in traditional agricultural price and income support programs, and governmental responses to climate change could all significantly affect land allocation decisions by some private landowners.

5.4.2 Land-use model estimation

Drawing upon the land-use theory, this section presents the three basic types of econometric land-use models that have been estimated for RPA Resource Assessment analyses. The structure of the empirical models is determined by the data used for estimation and the research question, which suggests the following categorization: (1) aggregate data models, (2) randomly sampled plot-level data models, and (3) spatially explicit data models.[3] The first type represents the aggregate areas of land in given uses within specified geographic areas, such as counties. For example, Ahn et al. (2000) model the shares of land devoted to forest, agricultural, and urban and other uses in counties in Alabama. The second type uses plot-level data to represent the land-use decisions of individual landowners. Lewis and Plantinga (2007) use plot-level data from the NRI to model the decisions of private landowners in North Carolina and South Carolina to allocate land to forest, agriculture, and urban uses. The third type of empirical model uses spatial information, with examples reported by Lewis and Plantinga's (2007) and Plantinga et al.'s (2006) use of parcel data and Alig et al.'s (2005) use of census tracts.

5.4.2.1 The basic shares (aggregate) model in the area-base approach

Most of the earlier land-use models developed for RPA Resource Assessments are the first type of econometric area-base model and have been estimated with aggregate data. Area-base models describe

[3] The discussion in Section 5.4.2 is based in part on Plantinga and Irwin (2006).

proportions (or shares) of land in forest, agriculture, urban, or other discrete use categories, within well-defined geographic areas, usually counties, as functions of socioeconomic and geophysical variables aggregated at the particular geographic unit of analysis. Published examples are numerous (e.g. Alig 1986; Alig and Healy 1987; Alig et al. 1988; Lichtenberg 1989; Plantinga et al. 1990; Stavins and Jaffe 1990; Parks and Murray 1994; Plantinga 1996; Hardie and Parks 1997; Mauldin et al. 1999a; Plantinga et al. 1999a). Appendix 5 summarizes the sources and types of aggregate data used in such models.

One approach (e.g. Mauldin et al. 1999a) is to employ a logistic parameterization of the expected share p_{ikt},

$$p_{ikt} = \frac{e^{\beta_k' X_{it}}}{\sum_{s=1}^{K} e^{\beta_s' X_{it}}} \tag{5.3}$$

where i, k, and t are county, land use, and time indices, respectively, X_{it} is a vector of explanatory variables, β_k is a vector of unobserved parameters to be estimated, and K is the number of land-use alternatives. The observed land-use share, y_{ikt}, is specified as an additive function of the expected share and a mean zero error term ε_{ikt}. The logistic specification in (5.3) is convenient because it restricts the expected shares to the unit interval and the transformation of the model (see, e.g. Judge et al. 1988, Chap. 19),

$$ln\left(\frac{y_{ikt}}{y_{i1t}}\right) = \beta_k' X_{it} - \beta_0' X_{it} + \mu_{ikt} \tag{5.4}$$

where μ_{ikt} is the transformed error term, is linear in the model parameters. The K-1 sets of parameters are identified if $\beta_0 = 0$.

In many applications, the model in (5.4) is estimated with pooled times-series and cross-sectional observations. For instance, Hardie and Parks (1997) estimate a model using county-level observations of irrigated farmland, other farmland, and forest land shares for five states in the Southeast and the years 1982 and 1987. The share of land in urban and other uses is calculated as the difference between the total land area and farm and forest land. The independent variables include crop revenues and costs, timber prices and costs, land-quality measures, and sociodemographic variables such as average age of landowners, population density, and per capita income.

According to the theory discussed above, the aggregate amount of land allocated to a given use should depend on the net economic returns to alternative uses. The manner in which land rents or net

return measures are constructed is a function of the underlying decision problem. In many studies, the decision to allocate land to agricultural uses is viewed as a static problem. Landowners observe input costs at the start of the growing season, form expectations of prices for output they will receive at the end of the season, and allocate their land to the use yielding the highest expected profits. Provided that capital investment decisions (e.g. investment in long-lived capital such as farm machinery and natural capital such as soil fertility) are independent of land-use decisions, the allocation problem is identical in each year and unrelated to allocation decisions in other years. In this case, researchers simply include rent variables corresponding to the year of the land-use observation. For instance, Miller and Plantinga (1999) estimate crop share models for Iowa and include lagged crop prices (the lagged price is assumed to be expected price) and current fertilizer costs.

When forestry is a feasible land use in addition to agriculture, the allocation decision involves a dynamic problem. As noted above, under certain conditions this problem is a simple comparison of present values of net returns to alternative uses. Present value measures of forestry and agricultural returns are included in econometric models estimated in Alig (1986), Stavins and Jaffe (1990), Parks and Murray (1994), Plantinga (1996), and Mauldin et al. (1999a).

Data on returns to urban uses of land are not widely available and, instead, researchers include proxies for urban rents in shares models. One commonly used proxy measure is population density. Lubowski (2002) assembled one of the more advanced measures by using annual urban net returns estimated as the median value of a recently-developed, one-acre parcel used for a single-family home, less the value of structures, annualized at a 5% interest rate.

When cross-sectional data are used, it is necessary to control for any systematic differences across counties. Differences in physiographic characteristics of the land are particularly important because land-use decisions are often closely tied to the quality of the land for particular uses. Before land-quality data were widely available, Alig (1986) stratified regions by physiographic region (e.g. mountains) to reflect differences in characteristics of the land across the Southeast. Later, researchers used more detailed data to investigate how quality of land affected allocations, such as allocating higher quality land to intensive agricultural uses such as row cropping while low-quality land was often put into forestry. Land-use shares for an individual county will,

therefore, depend on the distribution of land quality within the county. In most applications, researchers include variables to characterize this distribution. For instance, Mauldin et al. (1999a) and Ahn et al. (2000) construct measures using county-level data on Land Capability Class ratings.

An assumption implicit in the basic shares model is that landowners can change uses costlessly. Although the cost of converting land from one row crop to another may be approximately zero, the costs of moving between agricultural, forest, and urban land uses are, in many instances, likely to be substantial. Modifying the shares model to account for conversion costs is difficult due to the aggregate nature of the data. The land-use observations reveal net changes in land use but provide no information on transitions between uses. For instance, over a given time period, one may observe a change in forest land area and an equal and opposite change in agricultural land area. This may be the outcome of a simple shift of land from agriculture to forest, but an infinite number of more complicated land-use transitions can produce the same result. Data from the NRI indicate that net change statistics often mask more complex sets of transitions. Stavins and Jaffe (1990) and Plantinga and Ahn (2002) represent these dynamics using combined cross-sectional and time series observations of aggregate land-use shares. Another approach, discussed next, is to model plot-level land-use decisions, in which transitions between uses can be observed directly.

5.4.2.2 Plot-level data models

The most comprehensive set of plot-level land-use observations is provided by the NRI database (USDA NRCS 2001). The NRI database provides detailed land-use and land-quality information on approximately 800,000 randomly selected plots at four points in time (1982, 1987, 1992, and 1997). The same plots have been surveyed in each of the four years, thus providing observations of land-use transitions. Plot-level land-use observations are also available from FIA inventories. However, as discussed above, the FIA data do not include detailed information on nonforest uses.

Lubowski (2002) uses the national NRI sample to model the probability that land is allocated to cropland, pasture, forest, urban, range, or the Conservation Reserve Program. The dependent variable in the econometric model is the choice of land use in year $t + 5$ (t $=$ 1982, 1987, 1992) at each NRI plot and the independent variables are the

land use in year t, the land capability class rating of the plot, and proxies for the expected net returns from the land-use alternatives as of year t. By assembling data from a variety of private and public sources, Lubowski (2002) constructed county-level estimates of annual net revenues per acre for crops, pasture, forest, range, and urban uses for all 3,014 counties in the 48 contiguous states. The net returns to cropland and timber are weighted averages of net returns to specific crops and forest types, where the weights reflect current cropping patterns and forest type distributions. Models are estimated using a nested logit specification (Train 2003). Lewis and Plantinga (2007) use NRI data and a similar modeling approach to estimate a land-use model for forest, agricultural, and urban land uses in North Carolina and South Carolina.

Approaches using NRI data can offer insights about transitions among land uses on the entire land base not possible with FIA data, because as noted above, the FIA inventories do not include detailed information on nonforest uses. Broad land-class designations, however, are recorded. Kline and Alig (1999) use FIA plot-level data for Western Oregon and Washington to estimate the probability that land changes from either farm or forest use to developed use between inventories. A discrete choice model is used and independent variables include forest and farm rents, sociodemographic characteristics of the county in which the plot is located, and variables indicating the presence of zoning restrictions.

The structure of plot-level models is similar to that of aggregate data models and, indeed, the plot-level model is equivalent to the aggregate data model under certain restrictions.[4] From an econometric and land-use modeling perspective, however, there are advantages to using plot-level data. First, to the extent they are available, variables measuring plot-level characteristics such as land quality can be included in the econometric model. In aggregate data models, these characteristics must be represented using less precise aggregate variables. Second, if plots are resampled over time, observations of land-use transitions are provided and, in principle, these can be modeled explicitly. At present, the NRI and FIA databases provide relatively few observations over time. As more time series observations are recorded, however, the relative advantage of using plot-level data will increase.

[4] The explanatory variables in the plot-level model are measured at the county level, and there is no explicit recognition of plot-level changes in land use.

5.4.2.3 Spatially explicit models

Spatial land-use models can be viewed as extensions of area-base models first developed by economists over 20 years ago. Future land-use shares are computed by using projected explanatory variable values and provide aggregate regional or national land-use projections commonly reported in national resource assessments. Although the spatial detail of such projections is limited to the geographic unit of analysis—usually counties—this has sufficed for national resource assessments. Ecologists, however, often desire land-use projections at finer spatial scales more relevant to ecological processes they study. The desire to account for land-use change in ecological analyses has led to the development of more spatially explicit models to project the rate and location of land-use change at finer spatial scales.

With the advent of geographic information systems (GIS) to store and organize geographically referenced data, spatially explicit land-use data at the parcel level have become more readily available. Increasingly, county tax auditors, state planning agencies, and other governmental entities are collecting and storing detailed data on parcel and building characteristics in an electronic format that has made it possible for researchers to compile parcel-level databases for counties. Attribute information from local tax assessment databases typically includes market transaction price(s), assessed values, current land use, zoning, lot size, location, and structural characteristics of any house or building on the parcel. In addition to public sources, parcel-level data for metropolitan areas may also be purchased from several national real estate companies.

Other geographically referenced data, including roads, cities and towns, recreational areas, soil quality, slope and elevation, cities and towns, school districts, etc. can also be acquired and overlaid with the parcel data using GIS to generate a host of spatial variables to be used in econometric models. Again, availability of these data for a particular region varies greatly across states and sometimes across counties. Some of these data are available from federal government sources, for example, the US Census Bureau maintains Tiger Line files, from which roads, hydrology, census tracts, and other geographic features can be extracted. Other federal government sources of GIS data include the US Geological Survey, the Environmental Protection Agency, and the US Department of Housing and Urban Development.

Although these data make it possible to model land-use conversion at the level of the individual decision-maker (e.g. Lewis and Plantinga 2007), acquiring and managing these data can be challenging. The availability of these data differs tremendously from state to state and, in many cases, from county to county. Often government agencies save only the most current information, so changes over time in land use and other attributes can be much harder to piece together. For example, local agencies do not always track a residential lot's subdivision history, so the researcher must piece together which subdivided lots comprise the original unsubdivided parcel. Because just one county will typically contain tens, and sometimes hundreds, of thousands of parcels, management of these data requires a GIS to store and organize data and to generate spatial variables.

Spatially explicit models of land use include those that explain land use, land values, and land-use conversion. All three types of models begin from the assumption that land is a heterogeneous good, comprised of a bundle of characteristics, and that the land use, value, or change can be estimated as a function of the parcel's characteristics. An advantage of using parcel-level data in modeling land-use change is that the data are at the same level of resolution as the economic agent who makes the land-use conversion decision. This avoids problems of aggregation and the need to assume a representative agent; it also allows for a much more detailed investigation of land-use pattern and change. In addition, because data are available for a contiguous area, models can be estimated that account for spatial processes of land-use change and spatial interactions among nearby parcels. An important econometric issue that arises in the estimation of these models is the likely spatial autocorrelation of the error terms, which arises due to measurement error or unobserved variation that is positively correlated over space.

What economists have come to call "spatial" land-use models generally rely on discrete land-use data sampled from satellite imagery, aerial photographs, or systematic land inventories, combined with other spatial data describing socioeconomic and geophysical variables. These data are used to estimate logit or probit models describing the likelihood of a particular land-use change occurring at a given location and point in time (e.g. Bockstael 1996; Wear et al. 1996; Nelson and Hellerstein 1997; Wear and Bolstad 1998; Kline and Alig 1999; Kline et al. 2001).

5.4.3 Examples of regional models

In this section, we discuss examples of regional empirical studies and consistency with central findings of theoretical analyses that posit that relative land rents and land characteristics such as location and soil productivity determine land use. Given the quickly expanding number of studies since the early 1980s, we concentrate on a subset of studies for the North, South, and Pacific Northwest. One key point is that the state of the art in model development will continue to improve with enhanced data availability; the most comprehensive model is now represented by the national-level work of Lubowski et al. (2006) and Plantinga et al. (2006) in support of the 2010 RPA Assessment.

5.4.3.1 Examples of land-use models for the North

Within the North region containing 167 million ha, area-change model development for RPA Timber Assessments has concentrated on the Lake States and Maine due to relative importance of the forest resources. The earliest published studies were by Plantinga et al. (1989, 1990) that produced a model of private timberland area as a function of the level of timberland, changes in rural population, level of rural population, and household income. Later, Plantinga's (1996) results for a 14-county area in Wisconsin showed that land quality and a broader set of land rent variables could be included in land-use models for the broader Lake States region. Mauldin et al. (1999b) then constructed a land-use model for the region based on landowners allocating parcels to the use providing the highest land rent, and with land-use patterns influenced by soil quality. Land-quality measures were constructed from the NRI data on soil characteristics that largely became available since the Plantinga et al. (1989) study. Mauldin et al. (1999a) found that land quality does not significantly affect urban land-use patterns.

For Maine, the state with the highest percentage of forest cover (approximately 95%), the earliest land-use study for RPA Resource Assessment was estimated by Howard and Lutz (1991). They estimated both individual state models and one for a Northeastern region that included Maine, New York, and Pennsylvania—the three most important states in terms of forest resources in the region. Their model was generally similar to area-change models estimated for other regions, such as Alig's (1986) and Plantinga et al. (1989), but did test stock market index and pulping capacity as explanatory variables.

Similar to the case for the Lake States, Mauldin et al. (1999a) then constructed a land-use model for Maine based on landowners allocating parcels to the use providing the highest land rent, and with land-use patterns influenced by soil quality. They also included travel time to the New Hampshire border to reflect costs of transporting agricultural commodities and wood products. Similar to the Lake States findings, Mauldin et al. (1999a) found that land quality does not significantly affect urban land-use patterns in Maine. Coefficients on travel time variables largely conformed to expectations: more remote counties (i.e. those farther from Portsmouth, New Hampshire) tended to have less agricultural and urban land and more forest land.

For the North, the studies lend support to the theoretical and empirical findings that land-use patterns are determined by relative rents and land quality. The coefficients on land rent variables in the econometric model indicate that land tends to be allocated to the use providing the highest rents, and that the rents associated with a given use may affect the tradeoff between other uses. Furthermore, higher quality land tends to be allocated to agricultural uses, lower quality land tends to be forested, and land quality does not significantly affect urban land-use patterns.

5.4.3.2 Examples of land-use models for the South

Within the South, several studies were conducted in the 1980s and 1990s to investigate relationships between changes in timberland area and socioeconomic variables. As in the North, econometric studies were used to test economic hypotheses and develop empirical relationships between revealed landowner behavior, such as changes in land use, and explanatory variables such as government programs, timber prices, agricultural prices, and costs of different land management options (e.g. Ahn et al. 2001). The 216 million ha of land in the South were stratified by the two RPA/FIA regions of the Southeast and South Central.

As discussed earlier, the prototype area-change model by Alig (1985, 1986) estimated for the Southeast was applied in *The South's Fourth Forest* study (USDA FS 1988). A similar model was estimated for the South Central region (Alig et al. 1988), and the southern area models were used to support the periodic 1990 RPA Timber Assessment (Alig et al. 1990). For subsequent assessments, a land-use model was developed for the South Central region that described the relationship between the areas of land in different uses—private

timberland, agricultural land, and urban and other land—and determinants of land use (Ahn et al. 2001, 2002). Determinants include the net returns to land in forest and agriculture, population density, distance to closest metropolitan area, and land-quality measures. Observations for the 558 counties in the South Central region were from FIA inventories conducted since the 1960s. The agricultural share of land was defined as that in cropland and pasture, and county-level observations were gathered from the census of agriculture for 1964, 1969, 1974, 1978, 1982, 1987, and 1992. Ahn et al. (2001) used population density to explain the share of land devoted to urban and developed uses. In addition to population density, a distance measure was used to explain the share of urban and developed land. The rationale for the distance measure was the hypothesis that land in counties closer to a city (population $> 25,000$) have more potential for conversion to developed uses than do counties farther away. The distance variable was calculated as the distance from the town located in the center of each county to the closest city.

The estimation results included that higher forest rents are expected to increase the forest share of the land base and decrease the agricultural share. An increase in agricultural rents tends to lead to the opposite effect, with an increase in agricultural area relative to forest area. Population density and distance were significant variables in explaining the share of land devoted to urban and other developed land. Population density has a positive effect on the ratio of urban and developed land to forest land. Conversely, the effect of the distance measure on the same share ratio is negative, indicating that a county closer to a metropolitan area tends to have more urban and developed land relative to forest land.

For the 2000 RPA Timber Assessment, the econometric results for the South Central were used to generate land-use projections for the Southeast. In doing so, we assumed that landowners in the two southern regions respond in similar ways to changes in land-use determinants, specifically population and the net returns to forestry and agriculture. In support of this assumption, we noted that the regions are similar in terms of forest species, agricultural crops, and demographic characteristics. Later research by Plantinga and Ahn (2002) used time series and cross-sectional data on the South Central to estimate a model with Markov structure, thus explicitly representing the dynamics of land-use change.

5.4.3.3 Examples of land-use models for the Pacific Northwest West

Within the Pacific Coast region, the western portions of Oregon and Washington are some of the most productive timber growing areas in the world, but have experienced above-average population growth and land-use changes have affected the forest land base. For the 1990 RPA Timber Assessment, a linear proportions model for private timberland in Pacific Northwest (Parks 1988) was used to project timberland areas, and was supplemented by expert opinion (Alig et al. 1990). Per hectare incomes for forestry, crop agriculture, and livestock agriculture along with population density and urban population percentage were the explanatory variables in the projection model. Parks and Murray (1994) investigated other land attributes (e.g. physiographic characteristics, fertility) influencing timberland area changes in the Pacific Northwest, finding that land-use changes were not strongly correlated with returns from forestry. Area projections were constructed for western Washington in a special timber supply study (Adams et al. 1992). This was followed by an empirical model with more spatial relationships, developed by Kline and Alig (2001) describing the probability that forests and farmland in western Oregon and Washington were developed to residential, commercial, or industrial uses. Development probabilities were a function of spatial socioeconomic variables, ownership, and geographic and physical land characteristics, using a gravity model (Kline and Alig 2001). Geographically referenced data on historical land use were provided by the FIA Program.

The Kline and Alig (2001) projections were used in the 2000 RPA Timber Assessment. The model was used to project future land-use change and private timberland areas in western Oregon and Washington, based on projected values of population and other explanatory variables. The estimated model coefficients were used to compute the probability that sample plots would convert to an urban use over time. The computed probability that each plot is converted to an urban use is multiplied by the area expansion factor for each plot to estimate the area of timberland represented by each plot likely to be converted to an urban use. Land exchanges between forestry and agriculture were assumed to offset each other, based on recent historical data.

The need to consider spatial relationships has grown with increased populations across regional and national landscapes. Increasing population densities in forested areas may cause changes in timber management, including likelihood of timber harvest. With more people living closer to forests, fire suppression efforts and costs will increase. What

often is called the forest/urban or wildland/urban interface is characterized by expansion of residential and other developed land uses onto forested landscapes in a manner that threatens forestlands as productive socioeconomic and ecological resources. Prevailing hypotheses suggest that such forestlands can become less productive because forest owners reduce investments in forest management. Kline et al. (2003) developed empirical models describing harvest, thinning, tree planting, and forest stocking in western Oregon, as functions of stand and site characteristics, ownership, and building densities. They use the models to examine the potential impacts of population growth and urban expansion, as described by increasing building densities, on the likelihood that forest owners harvest, precommercial thin, plant trees following harvest, and maintain forest stocking. Empirical results support the general conclusion that population growth and urban expansion are correlated with reduced forest management and investment on private forestlands in western Oregon. Results have potential implications for both economic outputs and ecological conditions, as well as for wildfire risks at the forest/urban interface.

5.4.3.4 Sensitivity of changes in land use to market signals

One of the more important findings across regions for policy analysis of the early forest area studies revolves around sensitivity of changes in land use to commodity market returns. At one end of the range, Hardie et al. (2000) estimated land-use elasticities for forestland in the range of +0.35. This indicates that a 10% rise in timber prices would generate a roughly 3.5% increase in timberland, holding all other variables constant. This elasticity is in the same range as those found in the some other studies of land use in the South, although it is higher (more responsive) than estimates found in other regions(e.g. Parks and Murray 1994, for the Pacific Northwest).

In a recent comparison, the AREACHANGE model for the South had no statistically significant response to timber prices for the urban/forest interface and 0.1 for the forest/agriculture interface (Adams et al. 2005). In the Southern Forest Resources Assessment (Wear and Greis 2002), the elasticity of timberland area to timber price was about 0.3. Sensitivity of the planted pine response to timber price varied by owner, with elasticities of 0.60 for FI and 1.80 for NIPF owners. In the RPA Timber Assessment, NIPF owners exhibited an elasticity of area planted to pine with respect to timber price of 0.87 and zero for FI owners.

Relatively high land values for urban and developed uses compared to forestry (e.g. Alig and Plantinga 2004) and agriculture uses means that product prices for the latter uses are often dominated by those related to developed uses when modeling land use change. This economic hierarchy of land use meant that forestry and agriculture incomes were typically not significant in equations representing changes in developed land area, as shown by Alig and Healy (1987) and Alig et al. (2004). Alig et al. (2004) also reported elasticities, representing the estimated change in the proportion of developed land given a certain percent change in each explanatory variable, indicating that population density and per capita income had the largest relative influences on developed area.

5.5 PROJECTING LAND-USE CHANGES

Parameter estimates in the land-use models are used to project major land-use areas by decade. In general, assuming that the relationships between explanatory variables and land-use changes will not change over time, we then used independent projections of the economic and demographic variables to project the area of privately held timberland. One example of external projections of independent variables is drawing upon a common set of macroeconomic assumptions used in the 2000 RPA Timber Assessment (USDA FS 2001), including population and personal income projections. Changes in land rent variables imply changes in the proportions of the land base occupied in the future by major uses. Soil characteristics are assumed to remain essentially constant over the projection period used in the RPA Timber Assessment, so that land-quality variables are an example of a set of variables for which values do not change over the projection. Such applications involved in preparing land-use projections are discussed in Chapter 16.

5.5.1 Projections of exogenous variables

Assumptions pertaining to macroeconomic assumptions were provided by the USDA Economic Research Service (ERS) (USDA FS 2001). These included projections that real agricultural prices (at aggregate levels) would be constant to declining in the future, depending on the decade.

Timber price projections were taken from the overall Assessment System described in this book. Use of the timber price projections (e.g. Haynes 2003; Haynes et al. 2007) involves an iterative modeling process with other forest sector models. Iterative runs involve passing back and forth projections of related variables between models such as land-use changes and timber price projections until a satisfactory convergence is attained. Constraints are also applied in the land-use models based on analysis of historical rates of change (e.g. Alig 1985), expert opinion, and outside review to preclude illogical or unreasonable area trends for projected land uses/ownerships. Region-wide land-use trends are typically not quickly changed or reversed, given the slow rate of change of macro forces at work, capital limitations of owners, and the inertial nature of most land management.

5.5.2 Projection methods for land uses

The phase 2 amalgamation of econometric land-use models and area-change information from other studies represents a collection of regional projection methods that are tailored to regional characteristics and data availability. The second phase land-use models are composed of relations that allow direct computation of the dependent variables representing land uses, with no market or spatial equilibrium elements.[5] Econometric models are used in a simulation mode (e.g. SAS®software) to allocate total private land base within a region by major land use, given a fixed land supply and using projections of the exogenous variables described above. Projections from such regional models and other methods are collated in spreadsheet form, so that totals can be checked to ensure consistency with regional and national forest area estimates. This regional collection of projection methods is termed the AREACHANGE projection system.

Within the AREACHANGE projection system, land-use areas are projected in the first stage of the two-stage area-change projection, followed by forest type transitions on timberland discussed starting in Section 5.5. A regional example from the Southeast is used to illustrate the first stage of the area-change projection. The Southeast region contains the five Southeastern states of Florida, Georgia, North Carolina, South Carolina, and Virginia. The second phase land-use model projected areas for six major land uses or private forest ownerships:

[5] A phase 3 national model with market and spatial equilibrium elements is in process for the 2010 RPA Assessment.

crop agriculture, pasture agriculture, urban and developed uses, farm forests, miscellaneous private forests, and forest industry. Then, in the second stage, area changes are projected for five major forest types on the three private forest ownerships—planted pine, naturally regenerated pine, oak-pine, upland hardwoods, and bottomland hardwoods.

The model projects land use/forest ownership and forest type areas by decade for five decades, which corresponded with the planning horizon mandated in the RPA legislation. The model projects period by period, in a myopic fashion. This is in contrast to intertemporally linked allocations of the land base when the FASOM model (e.g. Adams et al. 1996) projects land use.

For the AREACHANGE system, the land uses/forest ownerships are projected simultaneously, with a total land base limit imposed so that projections cannot exceed a state's land area (Alig 1985). In the RPA Timber Assessment, areas of each private forest ownership (and forest type areas comprising a forest ownership) typically change in each projection period when projected by the AREACHANGE projection system. Outputs from AREACHANGE provide arrays of timberland area by region, forest type, ownership, and period for each management unit in the ATLAS model (discussed in Chap. 6). After the initial projection is prepared, iterative running of linked Assessment System models can be conducted to adequately capture market-related feedbacks, particularly those related to price and timber harvest vectors provided by other Assessment System models. See Chapter 8 and Haynes et al. (2007) for a more detailed discussion of the linkages and the handling of feedbacks among the constellation of models in the RPA Timber Assessment framework.

An example of tailoring to regional characteristics is Kline and Alig's (2001) projections for the Pacific Northwest West. They use SAS software to project areas of land uses, and the introduction of spatial analyses altered the approach to projecting land use changes. Population projections for all 95 cities used in the analysis were based on county-level projected population growth through 2010, state-level projected population growth for 2011 to 2025, and extrapolation from 2026 to 2050. Stumpage price projections were obtained from the Assessment System described in this book.

Another complication for the Pacific Northwest West model was testing simulations using the random-effects probit coefficients for the model that excluded roads as developed uses to compute the probability that each FIA sample plot will convert to an urban use at each

model time step. The computed probability is multiplied by an area expansion factor for each FIA plot to estimate the area of land represented by each plot that is projected to be converted to an urban and developed use at each time step in the model.

For regions where formal area-change models were not available from the second phase work, we prepared projections of forest area change based on several sets of data and information (Alig et al. 2003).[6] This included trend extrapolation for forest area changes compiled from FIA time series of data. For example, by region, we examined historical forest area trends by major ownership, along with trends for other major land uses, agricultural prices, population, and per capita personal income. Areas of forest land were then projected assuming a continuation of the patterns shown in the historical data. We then searched the literature for any forest area projections from other sources for any parts of the region with which to compare the basic form of the projections. We then reviewed information about major competing land uses, e.g. urban and developed use trends. Models of developed area were used to inform the projection of all major uses, by first subtracting projected developed areas from the total land base area for a region without a formal land-use model, e.g. Rocky Mountains region. For analyzing the likely competition between forestry and agriculture as major uses for the remainder of the private land base, we used projections of the FASOM model (Adams et al. 1996; Alig et al. 1998). The resulting regional forest area projections were then reviewed by various experts (from government, industry, and academia) who were familiar with the forestry situation in that region. Projections were then revised as appropriate in response to review comments.

5.6 LAND-COVER MODELING

The second stage of projecting forest area changes involves modeling forest type transitions to reflect area exchanges among major forest cover types. Failure to account for forest type changes over time can lead to miscalculation of resource production and errors in policy design. Timberland value and productivity depend in part on the

[6] For phase 2, such regions included all or parts of the Great Plains, Intermountain, Northeast, Pacific Northwest Eastside, Pacific Southwest, and North Central (Alig et al. 2003).

species of trees that are on the site or could be introduced through regeneration after timber harvest. Because physiographic differences exist between regions, forest types often differ as well.

5.6.1 Type transition theory

Studies of changes in forest types can be separated into three categories according to emphases on driving factors: (1) forest succession and natural disturbances, with emphasis on natural forces; (2) planned changes, based primarily on expected financial returns from timber management; and (3) empirical studies of forest type transitions based on observed regional trends, combining elements of forest succession and economics of human-caused disturbances. The first category of forest succession models is predicated on ecological theories of forest succession. Regional forest vegetation dynamics have largely been studied using forest succession models, concentrating on describing and predicting long-term phytosociological changes in undisturbed systems (e.g. Shugart 1984). Most models of forest development and succession assume a relatively stable, long-term community (e.g. Waggoner and Stephens 1970; Shugart et al. 1973). Succession is viewed as a dynamic, steady-state adjustment to a given environment, while disturbances are conceptualized as exogenous changes setting back forest succession. The second category of models brings in human-caused factors, but in a normative way or according to preset rules, e.g. what is optimal or prescribed. Most timber harvest scheduling models (e.g. FORest PLANning (FORPLAN)) adhere to this structure. Eng (1992) extends this for harvest scheduling models by incorporating stochastic elements in the modeling of cover type changes for public forests in the Pacific Northwest.

The third category of studies pertains to forest type transitions defined as shifts in areas of forest cover types because of either natural forces or human activity, e.g. timber harvest followed by tree planting. This approach combines elements of the other two categories, and tests forest type transition theory using observations from remeasured forest survey plots. This is the approach used in the RPA Timber Assessments. Such studies recognize that the role of disturbances in governing composition of major forest cover types is in the deflection of stand development from some natural successional pathway. These studies also recognize the stochastic outcomes associated with ecological processes, such as uncertain stand establishment and progression in forests, with significant changes in cover type that are

possible after timber harvests. This is consistent with a mixture of natural and human-related disturbances shaping forest developmental processes (Alig 1985; Brooks 1987). For example, economic factors not only affect the total land area allocated to forest cover, but through the impact of forest management practices, profoundly influence the ecological processes of forest stand development.

Our modeling approach is to use a quantitative modeling framework based on a broad consideration of ecological and economic principles (Alig 1985; Alig and Wyant 1985). This includes consideration of market signals (e.g. timber prices) in influencing forest type areas for a region. We estimated models empirically to gauge the relative importance of ecological and economic factors in influencing forest type transitions.

5.6.2 Type transition model estimation

We used three sets of inputs to project forest cover type transitions for the South: (1) original state or distribution of forest type areas, segregated by owner and subregion; (2) probability of application of three disturbance categories; and (3) conditional transition probabilities for a forest type's destination in response to receiving one of the three types of disturbance (Alig 1985; Alig and Wyant 1985).[7] The basic approach is illustrated with a probability tree (Figure 5-2). The conditional forest type transition probabilities are multiplied by the disturbance probabilities and the initial area in a particular forest type for an ownership (equation 5.5). In equation 5.5, we show the example of the planted pine type, illustrating area gains and losses linked to other forest cover types.

$$PP_{i,t+1} = \sum_{j=1}^{5}\sum_{k=1}^{3}(D_{i,k,t})(FT_{i,j,t}|D_{i,k,t})FC_{i,j,t} \tag{5.5}$$

[7] The discussion here centers on the forest type transition research in the South, which at a regional level has ten times more private timberland than the Pacific Northwest West. The forest type transition research initiated in the early 1980s for the South was followed in the late 1990s by model development for the Pacific Northwest West (Alig et al. 2000) and the Lake States, and applied in the 2000 RPA Timber Assessment. In other regions, data limitations resulted in the use of forest type transition probabilities representing an average over all disturbance regimes.

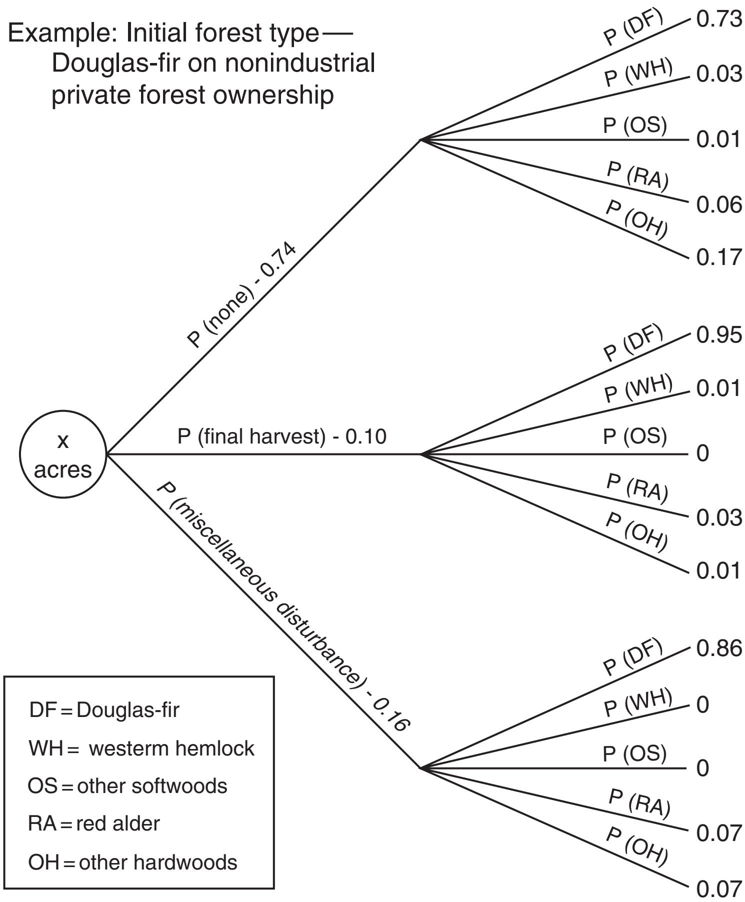

Figure 5-2. Probability tree for forest cover type transition example in the Pacific Northwest West.

where PP = area of planted pine for ownership i at time $t+1$

i = ownership ($i = 1, 2, 3$)

j = forest type in the South ($j = 1 \ldots 5$)

k = type of disturbance ($k = 1, 2, 3$)

D = probability of disturbance type k for ownership i at time t

FT = conditional forest type transition matrix; and

FC = vector of areas of forest cover type at time t.

In each time step, timberland gain and loss vectors are used to adjust forest type areas to reflect increments or decrements in area from the first stage of projecting land-use changes. The vectors are based on historical probabilities from forest surveys of gains or losses of timberland by forest type and ownership (Alig and Butler 2004a). The forest type gain vector describes the allocation of forest types among timberland that is gained from nontimberland land uses. The forest type loss vector describes the allocation of forest types among timberland that are lost to nontimberland land uses. When timberland was gained, it was most likely to be planted pine in the Southeast and upland hardwood in the South Central (Alig and Butler 2004a). Upland hardwood and natural pine were the most probable forest types to be lost when land was deforested.

Transition probabilities in the forest type transition matrices are conditional upon three sets of disturbances: no harvest, partial harvest, and final harvest (Alig and Butler 2004b). Probabilities of forest type transition in response to each type of disturbance reflect natural successional forces interacting with human-caused activities. The disturbance probabilities and forest type transition matrices represent the major processes affecting forest composition and structure and are a further refinement of the Markov chain method described by Alig and Wyant (1985). Each of these vectors and matrices were calculated from time series of forest survey data consisting of remeasured plots (e.g. Sheffield and Thompson 1997) and were calculated separately for the Southeast and South Central and each private ownership category.

The disturbance probabilities represent the likelihood that a disturbance will occur in a given time period. The final harvest probability vector is the proportion of area of a given forest type in which all merchantable trees will be harvested in a year. The partial probability harvest vector is the proportion of area of a given forest type that will be partially harvested in a year. The no-harvest category captures changes due to succession, natural disturbance, and nonharvest human disturbance processes.

A forest type transition matrix is a state/fate matrix that represents the probability of a given forest type (state) becoming a different or remaining the same forest type in a subsequent time period (fate), conditional on a final harvest, a partial harvest, or no harvest. To calculate these matrices, the areas of each state/fate combination were obtained from regional forest inventory data with the state forest types as rows and the fate forest types as columns. For example, one of the elements of the final harvest area matrix for the other private

ownership category in the South represents the area of natural pine (state or row) that converted to planted pine (fate or column) following a final harvest in a remeasurement period. These area matrices were converted to probability matrices by dividing each element by the row/state total, i.e. the total area of that forest type in the earlier time period.

In addition to the forest inventory-based matrices, data from surveys conducted by the American Forest & Paper Association (AF&PA 1999) and Moffat et al. (1998) were used in the 2000 RPA Timber Assessment in making projections for the FI and NIPF owners, respectively. These survey results were combined with inventory-based data to make projections. In particular, based on expert opinion and review meetings, final harvest matrices from the surveys were combined with inventory-based matrices using relative weights of 60/40 and 50/50 for the surveys by AF&PA and Moffat et al. respectively. Heavier weights were given to the AF&PA inputs because their estimates reflect future intentions, whereas the FIA estimates reflect past behaviors (Alig and Butler 2004a). All other matrices and vectors were based on forest inventory data.

Forest type transition matrices for the no-harvest case showed relatively low annual probabilities that any given forest type would transition to a different forest type across all ownerships and subregions. On average, it takes over 100 years for a forest to transition to another forest type in the absence of a harvest. Oak-pine had the highest annual probability (6%) of transitioning to another forest type. On FI lands, planted pine was the most common forest type to which oak-pine transitioned, whereas oak-pine on miscellaneous corporate and other private timberlands most commonly transitioned to natural pine and upland hardwood. These transitions are a result of oak-pine being a relatively "unstable" forest type, and slight changes in stand stocking can result in reclassification of the forest type. The mechanisms for these changes include succession (e.g. hardwoods replacing pines on a site) and human intervention, such as chemical applications to control vegetation (e.g. hardwood control in pine plantations).

The probability of a forest type transition following a partial harvest varies by forest type and subregion. Lowland hardwood has the highest and oak-pine has the lowest probabilities of remaining the same forest types following a partial harvest. The oak-pine forest type tend to transition to the upland hardwood forest type, whereas

the other forest types tend to transition to oak-pine. Probabilities of transitions to other forest type following partial harvests of planted pine and natural pine are higher in the South Central subregion than in the Southeast.

Forest type transition probabilities for a final harvest vary significantly by forest type, ownership, and subregion (Alig and Wyant 1985). The lowest probabilities for a forest type remaining in the same forest type after a final harvest are for natural pine. About one-fifth on average of the area of natural pine that is final harvested remains in natural pine across all private ownerships. The highest probabilities of forest types remaining in the same forest type following final harvests are for lowland hardwood and planted pine. Planted pine and upland hardwood are the most common fates for transitions of forest types after final harvest. As for regional and ownership influences, the probabilities that planted pine would remain in planted pine following a final harvest are much higher in the Southeast and for FI and miscellaneous corporate owners. The forest type transition matrices from AF&PA (1999) and Moffat et al. (1998) show similar trends to the inventory-based matrices, with the exception that the AF&PA and Moffat et al. matrices show higher retention of planted pine and higher transition rates to planted pine.

Given the importance of harvests in forest type transitions, feedback loops in our projections as part of phase 2 RPA area-change modeling incorporated disturbance probabilities and market price signals from other parts of the national timber supply modeling network (discussed in Chaps. 2 and 8) that project timber prices (e.g. Adams and Haynes 1996). We adjusted projections of planted pine area at certain time steps if subsequent projections for southern timber prices were significantly higher than used in the original model run. We drew upon recent elasticity estimates from the tree planting study by Kline et al. (2002), which give the percentage change in planted pine area for a corresponding percentage change in southern timber prices. The response is inelastic in that the change in planted pine area is less than the corresponding percentage change in southern timber prices. This is true partly because private owners may alter use of other nonland inputs (e.g. fertilizer) in response to timber price changes.

The linkage of models described above was facilitated by movement to an area-based modeling system regarding forest inventory. The transition from forest resource inventory models based on diameter-class projections to models based on timber yields per unit of area

in the 1980s allowed better accounting for forest resource changes resulting from land-use change, increased forest management (e.g. plantation establishment), or changes that are the result of natural succession toward climax forest types. Research by Alig (1985) and Brooks (1987) for the South were part of this transition to area-based forest resource projection models. Brooks (1987) used a model for the South—Southern Pine Age Class Timber Simulator (SPATS)—to examine the impact of alternative policy and planting strategies, including a component to project timber yields per unit area by age class. The SPATS model was linked to the TAMM model, described earlier in Chapter 3. About the same time, development of a predecessor to the ATLAS model, the Timber Resource Inventory Model (TRIM) (Tedder et al. 1987), included timber yield projection capability, using forest survey plot data with flexible (user-determined) aggregation schemes. The TRIM model was designed to be flexible to handle projections for any region, while the SPATS model was designed to model only the private forests of the South, and although the data for SPATS are also derived from forest survey plot data, they are aggregated outside the model. The SAM model (Alig 1985) and the TRIM model were applied in a linked fashion in *The South's Fourth Forest* study, along with other Timber Assessment models described in earlier chapters. After the special study for the South, the TRIM model was replaced by the ATLAS model for use in national Timber Assessments, as discussed in Chapter 6.

5.7 MODEL VALIDATION

Validation here refers to evaluating an area-change model's structure and behavior in comparison to the structure and behavior of the referent system to increase confidence in the ability of the projection to provide reliable information or insights for analyzing policy issues. Validation addresses several questions pertaining to model application and utility: (1) whether the area-change model is appropriate for it(s) intended uses; (2) whether the benefits of improving performance exceed the costs; (3) whether the model contributes to making better decisions; and (4) possibly how well the model performs compared to alternative models. The general objective of the AREACHANGE research has been to develop a projection system that can project long-term area changes for major land uses and major forest cover types

to support multiple resources planning in national RPA Resource Assessments. The primary application is for the long-range evaluation of impacts of a broad range of external forces, such as population growth on land base shifts. The ultimate concern is with policy decision-making and the value of related policy analyses, which is directly related to the reliability of projections of long-term changes on the land base. This is also helped by evaluation of the sensitivity of model outcomes to variations in input data, major assumptions, and completeness of model specification. For example, if the model outcomes are relatively unaffected by model refinement, those incremental costs are not justified.

Validation exercises can vary widely, including comparison of model solution vectors with corresponding real world vectors. In a practical sense, validation is very difficult for long-range models where outcome sets for comparative purposes are generally not available. Therefore, developers of area-change models have performed validation exercises to evaluate the goodness of fit of model simulations over historical periods. Ideally, to evaluate predictive ability, sufficient observations would be excluded from use in parameter estimation and used to evaluate the forecasting ability of the model. However, land-use data are relatively limited, and area-change studies have typically had to use all observations for parameter estimation (e.g. Alig 1985; Kline and Alig 2001). As an alternative, researchers have used model predictions for historical periods to examine a model's predictive ability. For example, Alig (1985) evaluated model performance for a model of land-use change in the Southeast over a 36-year period. Overall, the model appeared to predict with reasonable accuracy. In this case, explanatory power varied by physiographic region, e.g. the Coastal Plain model had higher predictive performance than the Mountains region variant.

One of the simplest ways to evaluate the potential accuracy of model performance is to examine the percentage of correct within-sample predictions (e.g. Kline 2003). In fact, such statistics routinely are provided as default output from most econometric software packages that offer those statistical procedures (e.g. logit and probit) most commonly used in recent years to estimate land-use models. Additional model validation indices computed using within-sample predictions have been proposed by Wear and Bolstad (1998) based on the work of Hauser (1978). They suggest that those indices can be used to evaluate the usefulness, accuracy, and overall significance of estimated models to predict future land-use categories.

A weakness in evaluating model performance based solely on within-sample predictions is that land-use change models most often are used to make projections of future land use that may involve explanatory variable values outside the ranges of those used to estimate the model. Greater confidence in model validation can be gained by additional procedures that reserve a proportion of sample observations from model estimation for later model performance testing (e.g. Kline et al. 2003). For example, the analyst might set aside, say, 10% of observations based on some random selection procedure, then estimate an empirical model based on the remaining 90% of observations. Model performance then can be evaluated by entering the explanatory variable values of the reserved observations into the empirical model to compute predicted values of the dependent variable that can be compared to the actual values.

Use of spatial data in constructing land-use models has increased sample sizes, for which part of the data set can be reserved for model projection evaluation. Kline et al. (2003), for example, estimated five auxiliary land-use models each based on roughly 20% of available observations. They showed that the estimated coefficients resulting from each auxiliary model generally fell within the 95% confidence bounds of the estimated coefficients resulting from a model based on the full data set, suggesting in their case that reserving some data for validation purposes may not overly influence model results. Additional analysis of each individual auxiliary model can be done based on within-sample predictions for each model as well as the validation indices proposed by Wear and Bolstad (1998).

One of the most intuitively appealing ways to evaluate the performance of empirical land-use models is either to compare their resulting within-sample predictions to historical trends depicted by other land-use data sets, or to compare their resulting projections of future land use to the projections of other land-use models previously estimated. For example, Alig et al. (2007) and Alig and White (2007) compare urban and developed area projections from three models, two based on NRI data for the dependent variable and the other using census urban data estimates. At both a national level (Alig et al. 2007) and a subregional level (Alig and White 2007), the developed area projections are largely consistent, all showing a substantial increase in developed area over the next several decades. However, care must be taken in using these validation approaches to consider whether differences in projected values owe to differences in models or to differences

in land-use definitions used in land-use data gathering procedures. Land-use models have been developed using the major sources of land-use data described in Appendix 5; however, because the major data sources each define particular land-use categories in different ways, the historical trends that their respective land-use data depict will not necessarily agree. Thus, evaluating model performance based on a comparison of the projections resulting from models based on different inventory data necessarily must include formal consideration of the specific criteria used by each data source to define land-use categories.

Sensitivity analyses were also used by Alig (1985) to investigate the robustness of the Southern Area Change Model. Long-term projections of area changes were influenced by different assumptions about population; however, this was limited somewhat by model constraints to preclude changes that would deviate significantly from recent historical trends. Other constraints were applied to preclude illogical changes for the land base, such as the absolute amount of land base occupied by a land use, and to assure that areas of all major land uses summed to the total land base area. Use of the constraints relied on expert opinion, because at the time the constraints reflected factors that had not been extensively researched (Alig 1985).

Another example of using sensitivity analyses to provide more information about area-change projections is described by Alig et al. (2004). They performed sensitivity analyses by altering projected trends in population density and personal income growth, two key assumptions obtained from exogenous sources. Substantial population growth in the USA has been associated with an increase in the rate of conversion of forest and agricultural lands to residential, commercial, and industrial uses (Alig et al. 1983; USDA NRCS 2001; Alig et al. 2003), increasing the importance of models that can aid in assessing future land-use scenarios, including sensitivity analyses. An example of an improvement introduced by systematic approaches was the elimination of possible double accounting of land-use changes when projections were done by sector (e.g. agriculture). With a total land base perspective and zero-sum constraints built in, systematic approaches ensured that land base totals would sum appropriately across sectors.

Ahn et al. (2000) tested the accuracy of predictions from a land-use shares model by assembling time series and cross-sectional data on Alabama counties and estimated shares models with a restricted

sample of the data. They then performed out-of-sample forecasts of land-use shares and compared these to the observed shares. They found that models with fixed effects (i.e. dummy variables for each county) produce the most accurate predictions. The fixed effects control for cross-sectional variation in the data, allowing the model parameters to capture the temporal relationships between the land-use shares and explanatory variables such as net returns.

For the type transition modeling, all data were used in model estimation, and the staggered nature of the source FIA data made it impractical to perform historical simulations. Model performance was reviewed by experts in several applications, including the *The South's Fourth Forest* study (USDA FS 1988), 1990 RPA Timber Assessment, and the 2000 RPA Timber Assessment. We have also compared projected forest type areas to actual outcomes, such as for private planted pine in the South, a critical variable in timber supply modeling. Comparisons indicate that the model was highly accurate, with a projection within less than 1% of the actual (Alig 2005).

Another set of projections for which actual outcomes were available in time to help influence future Assessment Systems development was Alig and Healy's (1987) projection of national developed area to the year 2000. Although some USDA personnel at the time thought that the developed projections were too high, and therefore implied too little forest and agricultural land in the future, the projections proved to undershoot the actual 2000 developed area by about 10%. Retrospectively, the cause of the undershooting was exogenous projections of economic activity that were too pessimistic compared to the robust US economic growth of the 1990s.

The validity of models in large-scale assessments is affected by the data aggregation schemes and the condensing of diverse and complex relationships into relatively few essential characteristics (Alig et al. 1984). The broad geographical range of most aggregate analyses invariably includes diverse forest owner classes, which have been impacted by increased activity by TIMOS, REITS, and land developers. The owners can have differing land ownership and management motivations, institutional constraints, resource and market knowledge, and other differences. Improvements in the quality and quantity of data have helped address some of the aggregation issues. This has included less aggregated geographic grouping with the increased availability of GIS-based data. However, changes in land use and land cover can result from the interplay of complex factors. Some causative

factors, such as landowner characteristics, cannot be measured cost-effectively over large areas. Further, sophisticated techniques of data manipulation and display do not offset the adverse effects of unreliable input data. Sensitivity analysis can be used to test the influence of input items on land use and land-cover projections.

A relatively large degree of uncertainty in land-use and land-cover projections is related to the estimation of future technological changes. This refers to both innovation and implementation of technologies across a diverse set of landowners. Substitution of other inputs for land in timber production is likely to increase in the future, somewhat similar to what has happened in agriculture, where a "green revolution" had impacts around the world. Precise forecasts of the rate and actual composition of the technical change are difficult to obtain. Expert opinions and outside review by experts of preliminary projections have been used to address the technology forecasting issue, while recognizing part of this is a judgmental matter. A key question in planning and implementing a land-use or land-cover study is whether the study approach is consistent and efficient in terms of the stated objectives, all within a general consideration of the costs and benefits of model development, implementation, and testing.

5.8 SUMMARY

The RPA Resource Assessments provide a broad array of area-based information about the Nation's forests and rangelands, including the current situation and prospective area changes over the next 50 years. Such information can help shape perceptions about whether we can sustain both increasing consumption of forest products and enhanced forest resource conditions (Alig and Haynes 2002). In addition to use in RPA Timber Assessments, projections of land-use and forest cover changes also provide inputs into other systems of resource models and analyses (Figure 5-3) that project land base conditions that affect policy issues such as changes in wildlife habitat, open space, recreation supply, and other natural resource conditions (USDA FS 2001).

Projections of area changes are accomplished in two stages: (1) projections of land-use changes, such as a shift from agriculture to forestry (where land use is defined as the purpose to which land is put by humans); and (2) projection of forest cover types, including planted pine, on land allocated to forestry use (where forest cover is the observed biophysical cover on forestland). The projection system

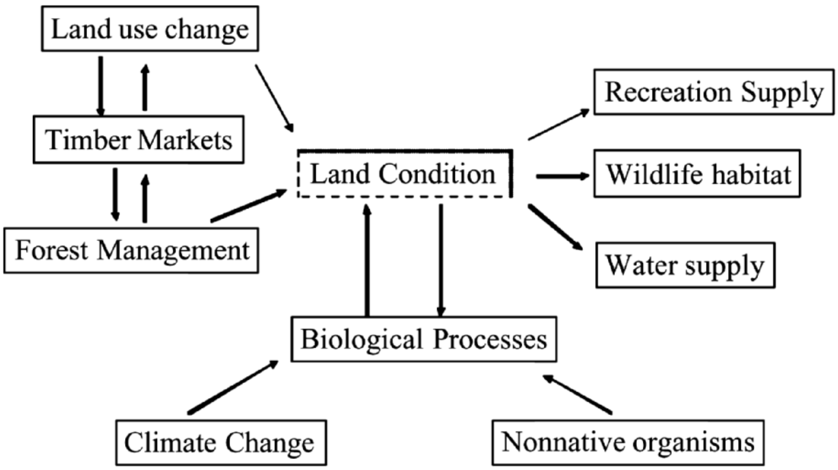

Figure 5-3. Schematic depicting conceptual framework for a land condition projection system.

is based on biophysical, ecological, and economic criteria, and includes detail on forest ownership classes. Area change models are linked to other Timber Assessment models described in other chapters, as discussed in Chapter 8.

During three phases of development, a number of econometric land-use models (e.g. Ahn et al. 2001) have been developed that supported past RPA Timber Assessments and other RPA Resource Assessments (e.g. wildlife), and active model refinements and extensions continue to support future RPA Assessments. Before the early 1980s, most existing resource assessments relied on expert opinion to develop projections of agricultural and forest land area (e.g. Wall 1981; USDA SCS 1989). Expert opinion approaches were supplemented first for the South with land-area projections obtained from an area-base econometric model (Alig 1985, 1986), in the first phase. Other applications of the area-base modeling approach in phase 1 followed (e.g. Parks 1988; Plantinga et al. 1989; Howard and Lutz 1991) in support of the 1989 RPA Resource Assessment. In the second phase, additional data sources and time series of data were utilized to enhance and update area-change models (e.g. Ahn et al. 2001) to support the 2000 RPA Timber Assessment. This included utilization of land-use data from nonforestry sources, as availability of additional quantities and types of data has been a major contributor to the expanded number of models developed over the last 25 years.

In the ongoing third phase, data from the NRI are being used to develop a national land-use model of transitions among major land uses. Moving beyond projecting net changes in forest area, the land-use transition model can project amounts of land going to forest use from other major land uses, and areas going out of forest use to other major land uses. Application of such land-use models to environmental and resource policy problems includes evaluating the costs of a national carbon sequestration program (Lubowski et al. 2006) and co-effects of terrestrial carbon sequestration (Plantinga and Wu 2003). County-level land-use projections help address the increasing need for more spatial resolution concerning issues such as forest fragmentation (Plantinga et al. 2006). With the advent of satellite imagery and GIS, other econometric land-use models have been estimated by using spatially referenced plot or parcel-level data (e.g. Kline et al. 2001). Spatial land-use models based on econometric estimation can be viewed as extensions of area-base models first developed by economists about two decades ago (e.g. Alig 1986; Hardie and Parks 1997). This will enhance utility of area-change projections for a broader set of RPA resource analyses (Joyce et al. 1986; Hof et al. 2006) and for other environmental policy issues (e.g. Alig et al. 2002; Butler et al. 2004; Alig et al. 2005).

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APPENDIX 5: LAND USE DATA

Aggregate data are available from a variety of federal government agencies that collect data on land use in the USA. From these sources, it is relatively straightforward to assemble a data set of aggregate times-series and cross-sectional observations. Land-use data are collected by various agencies for a variety of purposes. Land-use surveys generally differ in terms of statistical data-collection methods, scope, and a variety of other characteristics. No single land-use database provides universal coverage over space and time for use in addressing all relevant land-use policy questions (Alig et al. 2003). As noted in Section 5.2, econometric studies of land use that have fed into ARECHANGE modeling have drawn upon multiple sources of data. Next, because progression of area-change modeling has been heavily dependent on the availability of land-use data, we will describe five examples of data sources that we used: the FIA data assembled to support the 2000 RPA Resource Assessment by the Forest Service (e.g. Smith et al. 2001, 2004); the NRI by the USDA National Resource Conservation Service (e.g. USDA NRCS 2001), the Census of Agriculture by USDA, the US Census Bureau estimation of urban areas, and the Major Land Use Series (MLUS) by the USDA ERS (e.g. Vesterby and Krupa 2001).

A5.1 Census of agriculture

The Department of Agriculture conducts the Census of Agriculture, which provides county-level data on farmer-owned land. For instance, the Census of Agriculture reports the area of cropland (by crop type), pastureland, and woodland for each county and approximately each five years. Many agricultural states (Iowa, Wisconsin, etc.) collect

these data on an annual basis through state Agricultural Reporting Services.

A5.2 Forest inventory and analysis

The Census of Agriculture data on forest area are incomplete because they only report farmer-owned woodland. The Forest Service collects data on all forest land in the USA through its FIA units and national forest inventory units. During phases 1 and 2, FIA inventories were conducted on a state-by-state basis and on cycles in the 8–15-year range (currently, FIA inventories are conducted annually). The inventories provide county-level estimates of forest area, disaggregated by owner, species, and additional forest characteristics. Due to the nature of their sampling design, the FIA does not collect detailed information on nonforest uses. Thus, in applications where nonforest uses are of interest, Census of Agriculture data on agricultural land uses have been combined with FIA data on forest land uses to yield aggregate (county-level) observations (e.g. Hardie and Parks 1997; Mauldin et al. 1999a; Ahn et al. 2000).

The FIA surveys conducted by the Forest Service are designed to provide objective and scientifically credible information on key forest attributes, such as forest stocks, growth, harvest, and mortality. Related data are collected by region, forest ownership category (e.g. FI vs. NIPF), and cover type (e.g. oak-hickory), by using a sample of more than 70,000 permanent plots. The FIA inventories provide consistent forest inventory data for the Nation, back to 1952 (Smith et al. 2001). The FIA inventories in conjunction with the RPA Timber Assessment have resulted in a national summary data base, and which also incorporates other data from the US Census Bureau (total land area, population, etc.). Although sampling techniques for the NRI and FIA are similar, different sampling grids make the estimates from the two inventory systems statistically independent.

Alig et al. (2003) discuss differences in forest area estimates between FIA and other data sources, as well as complications due to reclassification of forest land over time by FIA due to changes in definitions and sampling procedures. For example, changes in definitions used in FIA surveys have also resulted recently in 2.4 million ha of forest in California being reclassified as nonforest. The FIA surueys are now being conducted annually rather than periodically.

The FIA inventory data are gathered by using photointerpretation and ground truthing on a systematic sample of plots defined as pinpoints on the ground. These data include land-use and ownership characteristics of sample plots, among other data. The land-use data were used in the Kline and Alig (2001) study of land use in Pacific Northwest West. However, the developed component of these land-use data are not reported at a national level, so they are not included in the section below concerning differences in definitions between urban and developed area estimates.

A5.3 National resources inventory

The NRI conducted by the USDA NRCS is designed to assess land-use conditions on nonfederal lands and collects data on soil characteristics, land use, land cover, wind erosion, water erosion, and conservation practices (USDA NRCS 2001). In addition to collecting data on about 300,000 area segments and about 800,000 points within those segments, a geographic information system is used to control for total surface area, water area, and federal land. The NRI is conducted by the USDA's NRCS in cooperation with Iowa State University's Statistical Laboratory (USDA NRCS 2001).

As a result of its statistical design, the NRI allows land-use transition matrices to be developed since 1982. With the exception of a few land-use categories, such as for urban uses, land-use shifts occur in both directions across the land-use categories. For example, some land moves out of the grassland category and into the cropland category during the same period that other cropland moves into grassland uses. This dynamic is captured in the so-called land-use transition matrices (USDA NRCS 2001). One can prepare land-use transition matrices for five-year periods between 1982 and 1997 for major land-use categories(e.g. Alig and White 2007).

A5.4 Major land-use series

The MLUS is an inventory of land developed from a variety of land-use surveys and public administrative records of land use. This long-term series was developed by the ERS (Vesterby and Krupa 2001), with ERS analysts constructing land-use estimates by collecting data from the Census Bureau, public land management and conservation agencies, and other sources. The MLUS is the only consistent accounting

of all major uses of land in the USA, public and private. Drawing upon data from various agencies means dealing with data on land use that can differ widely in definition, collection criteria, and area. Compatibility is sometimes hindered by changes in the characteristics of data available over time. The primary source of MLUS data pertaining to forest area is the Forest Service.

In addition, many additional sources of data exist on land use and land cover that are not used in the MLUS because they are not the most suitable for the purpose of comprehensively inventorying US land. For example, the US Geological Survey of the US Department of the Interior maintains satellite imagery of land cover at various points in time. Many of these data sources are better suited for other specialized purposes.

A5.5 USDC bureau of the census

The Bureau of Census (BOC) produces estimates of urbanized land area based on the population census. Prior to 1990, only state-level estimates are reported. The 1990 census, however, provides estimates at the county level. These estimates are not based on observed or reported land use but rather on population density within a specified geographic area. Thus, these estimates are not consistent with Census of Agriculture and Forest Service data because agricultural and forested land may be found within an area classified as urban. As an alternative, the area of land in urban and other uses can be computed as the difference between the total land area of a county and the agricultural and forest land areas.

A5.6 Differences in measures of forest area

Forest area is estimated differently across several of the major databases (Alig et al. 2003). The first measure is the FIA estimate of forest land area. The second measure is the estimate of “forest-use land” area given in the MLUS database of the ERS. The ERS classifies some forested land as “special-uses” land. In particular, “special-uses” land includes federal and state parks, wilderness areas, and wildlife refuges. Hence, “forest-use” land differs from the FIA “forest land” in that forest-use land excludes parks, wildlife areas, and similar special-purpose uses. The third measure of the area of forest land is the estimate presented in the NRI of the USDA NRCS.

The area of MLUS "forest-use" land is lower than the area of FIA "forest land" at all dates discussed by Alig et al. (2003). This is consistent with the exclusion of parks and other special-purposes land from "forest-use" land. Note also that the gap between FIA forest land and MLUS forest-use land has grown slightly over the last 60 years. This reflects the growth of wilderness areas and other forested special-uses land during this period. Second, note that the NRI measure of the area of forest land is only about two-thirds of the FIA measure, in that about one-third of the forested lands of the contiguous 48 states are federally owned. This fraction varies markedly between regions.

The second largest use of land in the 48 states is for forest use according to the MLUS database. This category is defined to exclude forested land that is not available for timber production because it is in special uses, such as national parks, but includes forested land that also is grazed. The 223.8 million ha in forest uses in 1997 account for almost 29% of the land in the contiguous 48 states. Approximately 56.7 million ha of this also is grazed.

The data sources differ in length of reporting period, complicating some comparisons of area changes across time. Both the FIA estimate of forest land area and the ERS estimate of forest-use area have decreased in the past half century. The summaries of FIA data for each assessment report that the area of forest land decreased by 1.7% between 1938 and 1997. The ERS reports that the area of forest-use land decreased by 7.2% between 1945 and 1992. Available only for a shorter period, the NRI estimate of nonfederal forest area increased by 0.2% between 1982 and 1997.